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APPLICATION OF VACUUM IN FERROUS METALLURGY

Almost for two centuries, since the beginning of industrial utilization of methods of the ingot steel production, the metallurgists have been trying to develop various methods of production of steel with the minimum content of such gases as oxygen, nitrogen and hydrogen.

P.P. Anosov paid special attention to preventing molten steel from contacting the air before and during the pouring. He conducted experiments of pouring steel directly through the bottom of the crucible, when the mold was placed on the crucible and the steel was poured into the mold by quick turning of this set upside down.

P.P. Anosov introduced lubrication of heated moulds with tallow considering that "gases produced by burning tallow prevent air from penetrating to the steel [1].

At the early stages of development of the Bessemer method, the application of manganese in various forms for deoxidation of steel was the only method of the manufacture of metal fit for further processing.

D.K. Chernov explaining the causes and the mechanism of gas blowholes origination in steel ingots and trying to find a way of eliminating this phenomenon stated that "if we could prevent the steel from overcooling and at the same time protect it from oxidation by the surrounding air, then this kind of pouring only, repeated several times, would almost completely free the steel from all the gases" [2].

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Improvement of deoxidation processes, utilization of charge materials with the minimum hydrogen content, application of oxygen in the converter methods of steel production - these are the means used by metallurgists for high quality steel production.

Development of modern super high speed transport, building of power stations utilizing nuclear energy, wide application of semiconductors in various devices, development of many branches of modern technology - are unimaginable without utilization of pure metals and alloys.

Production of pure metals and alloys became possible due to the utilization of vacuum furnaces, which allow us to conduct heats in air-tight chambers upon very low pressures. The present-day utilization of vacuum induction, arc and resistance furnaces is due to the fact that it is impossible to produce some metals and alloys of desirable composition in any other furnaces, on the one hand, and that by melting in vacuum we can radically improve the properties of steels and alloys as compared with conventional furnaces.

The most important task facing the high quality steel metallurgy - is development and industrial application of methods providing for production of steel containing the minimum of such harmful elements as oxygen, nitrogen, hydrogen and nonmetallic inclusions.

Application of vacuum is a basic means for successful solution of this problem.

While producing any kind of steel, the content of oxygen dissolved in it can be reduced by appropriate deoxidation. But this does not completely guarantee the low oxygen steel pro-

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duction. The oxides of deoxidizing elements, which are produced during deoxidation, though insoluble in molten metal, can substantially influence the properties of steel if they accumulate and remain in steel as a separate phase (nonmetallic inclusions).

The task of production of steel free from the nonmetallic inclusions in conventional furnaces is practically insolvable.

From currently used deoxidizers only carbon interacting with the oxygen dissolved in the molten metal produces gaseous oxides insoluble in metal. Equilibrium constant of decarbonization reaction
$$[C] + x[O] = CO_x(gas) \quad K_c = \frac{P_{CO_x}}{[C]^1 [O]^x}$$
 does not depend upon the pressure at a given temperature.

At stable equilibrium constant, decrease of gaseous phase pressure (carbon ^{mon}oxide mainly) naturally reduces the value of $[C] \times [O]^x$.

In other words, application of vacuum can increase deoxidizing ^{power} ~~properties~~ of carbon and thus make it possible to produce steel deoxidized by carbon only i.e. free from the products of deoxidation reaction.

In an experiment conducted by G.A. Gernyk [3] it was found that in producing transformer steel in vacuum induction furnaces the value of $[C] \times [O]^x$ varies from 0.00002 to 0.00007, while at 1600°C, carbon monoxide being at the atmosphere pressure, this value is equal to 0.0020 - 0.0025. The transformer steel was produced in a residual pressure of the furnace approximating 1 mm Hg. Consequently, such a lowering of pressure carbon monoxide resulted in almost one hundred times increase of deoxidizing power of carbon.

Keeping in mind that the steel produced contained 3% of silicon, it becomes evident that in the above mentioned conditions carbon proved stronger deoxidizer than silicon.

Molten metal deoxidation speed in vacuum is in a direct ratio to the speed of decarbonization, as shown on Fig.1. The fact that the speed of removing oxygen from metal is several times higher than the speed of decarbonization is very important for the practice of steel production. This dissimilarity between lowering of carbon and oxygen contents in a metal, considering the proximity of their atomic weights, can only be explained by the fact that a considerable part of oxygen is removed in the form of its compounds with sulphur and silicon as well as in the form of carbon dioxide, if we also consider rather low carbon content in the metal. Fig 2. shows change of the carbon, oxygen and sulphur content in molten metal kept in vacuum in an induction furnace of 150 kg capacity.

The given data prove that part of the oxygen is removed in the form of its compound with sulphur, and we can not speak of any other mechanism of sulphur removal, there being no slag on the surface of metal at that stage of the heat.

Low partial pressures of nitrogen and hydrogen in vacuum furnaces make it possible to remove these gases from the molten metal in which they are dissolved. Particles of nitrides and oxides suspended in the molten metal can also be removed during decarbonization, since the surface dividing carbon monoxide bubbles from the metal is the place where these suspended particles are adsorbed. Consequently application of vacuum enables us to produce steel with low oxygen as well as nitrogen and hydrogen contents.

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I. Influence of melting method
upon the properties of transformer steel.

Advantages of melting in vacuum were utilized in transformer steel production, which must have small hysteresis losses, low coercitive force value and high magnetic permeability.

To find out the influence of melting method upon transformer steel properties two groups of heats were conducted: - one in a conventional and the other in a vacuum induction furnaces [4] The residual pressure in the vacuum furnace was from 1 to 10 mm Hg.

Chemical analysis of steel of the two groups heats is given in table I.

As follows from the data of table I steel melted in vacuum is characterized by lower carbon, oxygen, hydrogen and nonmetallic inclusions content.

Basic properties of the transformer steel directly depend upon its oxygen content as shown on fig. 3. Similar dependence was found between properties of the transformer steel and its nonmetallic inclusions content.

While studying nonmetallic inclusions extracted from the steel by anode dissolution of it, it was found that inclusions in the steel melted in a conventional furnace are fine silicate particles containing more than 60% of alumina; in the steel melted in a vacuum furnace large silicate globubs were found containing about 90% of silica. What is more important, the nonmetallic inclusion particles extracted from the steel melted in vacuum proved nonmagnetic, as different from the inclusions found in

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the steel melted in a conventional furnace.

Fig. 4. shows microphotos of nonmetallic inclusion particles extracted by anode dissolution: a - from vacuum melted transformer steel, b - steel melted in a conventional furnace.

Lower nonmetallic inclusions content resulted in a large grain steel, without impurities accumulations around grains, as shown on fig. 5.

Finally, the watt losses of the vacuum smelted transformer steel proved to be 20 - 25% lower than those of the steel produced in a conventional furnace.

During the industrial tests of the suggested method, transformer steel with the increased silicon content (from 3.45 to 4.12 per cent) was produced *in a vacuum furnace of 150 kg capacity [57].*

The Steel was then machined on a cold-rolling mill into a band 0.32; 0.20 and 0.08 mm thick.

It is known that high silicon content in transformer steel makes the cold-rolling of it more difficult, especially when the rolling is conducted with high degrees of deformation. But the steel melted in vacuum, despite its high silicon content, and due to lower content of nonmetallic inclusions was easily rolled into sheets 0.08 m.m. thick.

Table 2 gives the coercitive force values after the final high temperature annealing of steel plates of various thickness. As can be seen from the table 2, the steel has high properties.

2. Influence of carbon upon stainless steel properties.

Chrome-nickel stainless steel of austenite class possessing high mechanical properties and resistant to many acids and al-

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kalis is widely used in modern technology. A serious drawback of this steel is its tendency to develop intercrystalline corrosion. This drawback of the austenite class stainless steel results from the presence in it of carbon in quantities which are beyond the solubility limit for this element at the room temperature.

The carbon solubility limit in a steel containing 18% of chromium and 8% of nickel amounts to 0.02 per cent. This steel produced in ~~the~~ furnaces, when ~~tempered~~ ^{quenched}, presents an oversaturated carbon solution in γ phase. Operating for a long time at high temperatures (in the proximity) of 500 - 850°C), or during its welding, the solid solution desintegrates releasing carbon or chromium carbide and iron. This results in an unequal distribution of chromium in the steel, origination of low chromium content regions which reduce corrosion resistance of the steel especially near the of grains boundaries. It is possible to eliminate the tendency towards the intergranular corrosion of steel containing 0.06 - 0.07% of carbon only by adding to it titanium, columbium or tantalum.

Chrome-nickel stainless steel of austenite class can resist intercrystalline corrosion if its carbon content does not exceed the solubility limit. Untill recently it was not possible to produce this steel with the carbon content lower than 0.06 - 0.07 per cent in the are furnaces, using ferrochrome produced by silicothermic methods and containing about 0.06% of carbon.

Only utilization of ferrochrome produced in a vacuum furnace and containing 0.01 - 0.03% of carbon made it possible to

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produce chrome-nickel stainless steel containing not more than 0.03 per cent of carbon. Steel with a higher carbon content was produced under similar conditions; in some heats titanium was used as stabilizing element [6]. Chemical analysis data for the steels that have been studied is given in table 3. Forged steel samples were subjected to thermal treatment - one half was quenched in water, the second half was quenched in water and annealed. Samples of steel containing 0.07 - 0.09% of carbon were heated to 1100°C before the quenching and those of steel containing 0.01 - 0.03% of carbon - to the temperature of 1020°C . Annealing of the samples was done by keeping them at the temperature of 650° for two hours.

The tendency towards the intercrystalline corrosion was determined on samples of quenched and annealed steel.

The samples of steel containing 0.07 - 0.09 % of carbon were subjected to boiling for 48 hours, and of the steel containing 0.01 - 0.03% of carbon for 72 hours, in a solution containing 110 gramm of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, 55 cm^3 of H_2SO_4 and 1000 cm^3 of water. The dried samples were knock-tested on a marble plate. Then each sample, secured in a vice, was bent by a hammer blow to the angle of 90° . Presence of cracks in the place of bend indicated that the steel is subjected to intercrystalline corrosion.

The quenched steel of all the heats proved resistant to the intercrystalline corrosion. The table 3 shows the results of determining the tendency of quenched steel to intercrystalline corrosion. The sign (+) marks the steel resistant to corrosion; the minus (-) marks steel subjected to corrosion.

The steel containing 0.07 - 0.09% of carbon proved affected

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by the intercrystalline corrosion after keeping it heated to 650° for two hours and then boiling it for 48 hours. The steel with the increased carbon content and with the addition of titanium proved resistant to corrosion after annealing and boiling for 48 hours.

No tendency towards the intercrystalline corrosion was traced in annealed steels containing 0.01 - 0.03% of carbon, after boiling them in the solution for 72 hours.

Presence of titanium in the chrome-nickel stainless steel reduces the harmful influence of carbon causing the intercrystalline corrosion.

Resistance of quenched and annealed steel to chemical corrosion has been determined by boiling samples in 60% nitric acid for four cycles, 25 hours each. The resistance to the action of boiling nitric acid was determined by the loss of weight during the separate cycles - $\text{gr/m}^2/\text{hour}$.

While determining the resistance of steel to general corrosion it was found that the quenched steel from all the studied heats possesses satisfactory resistance. But the steel of the heats 4202, 4203, 4204, 4205, 4206 containing from 0.01 to 0.03% of carbon has a greater resistance than the steel with a higher carbon content, and second, that the quenched steel containing titanium is less resistant to the general corrosion than the steel with the same carbon content but without titanium.

The table 3 gives the results of determining the resistance of annealed steel to the action of 60% boiling nitric acid.

The results of determining the resistance of steel to general corrosion after quenching, and after the quenching and annealing are given on fig. 6.

The steel of the studied heats is subdivided into 3 groups - first is the steel containing 0.01 - 0.03% of carbon, second - steel containing 0.07 - 0.09%, and the third - steel with increased carbon content and titanium.

The studied annealed steels differ greatly as regards the general corrosion resistance. Keeping of quenched steel containing 0.01 - 0.03% of carbon at 650° for two hours almost did not change the general corrosion resistance; the resistance of this steel annealed is practically equal to that of the quenched steel.

Considerably less resistant is the annealed steel containing 0.07 - 0.09% of carbon. After the second cycle a sharp decrease of corrosion resistance is observed. Annealing of this steel after the hardening results in a sharp decrease of the general corrosion resistance. Increased carbon content changed the character of surface failure of the samples-pinholes corrosion was observed. These spots of intensive local corrosion spreading all over the surface of the samples evidently cause higher losses of steel when it is boiled in nitric acid.

The least resistant to the general corrosion proved to be the annealed steel with an increased carbon content (0.07 - 0.09%) and with additions of titanium. Keeping it for two hours at 650°, after the quenching, led to a reduction in many times of its resistance to boiling nitric acid. Violation of homogenous structure of the solution due to release of titanium carbides during the annealing of quenched steel is the main cause of quicker desintegration of the steel containing titanium.

Consequently while neutralizing the harmful influence of carbon as regards the tendency of steel towards the intercrysta-

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lline corrosion, the titanium addition decreases the general corrosion resistance of steel.

Production of chrome-nickel stainless steel with an increased general corrosion resistance and also resistant to the intercrystalline corrosion is thus possible only with ferrochrome containing not more than 0.03% of carbon. Only in this case it is possible to produce high quality stainless steel without additions of titanium or costly additions of rare columbium or tantalum.

3. Application of vacuum in production of ferroalloys and metals.

Application of vacuum made it possible to solve the problem of production of ferrochrome containing not more than 0.03% of carbon. The research for developing of the production technique for this alloy was conducted by S.V. Bezobrasov [7], who studied the process of decarbonization of high-carbon ferrochrome in vacuum.

Chromium oxide, chromium ore, nickel oxide and silica were used as oxidants. Small rods of fine ground high-carbon ferrochrome and oxidant were kept for a certain period in a vacuum resistance furnace. As a result the carbon content in ferrochrome went down to 0.01 - 0.03 per cent.

It was found that in case of keeping the rods 30 mm high and 30 mm in diameter under the pressure of $5 \cdot 10^{-2}$ mm Hg, at 1250-1300°C, the decarbonization period lasts for 10 - 14 hours. Naturally, the rate of decarbonization directly depends upon the capacity of vacuum pump.

The table 4 gives data on refining of high-carbon ferrochrome in vacuum. *As initial alloy was used ferro-*

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chrome ~~reduced~~ containing (%):

C	Cr	Si	S	P
7.50	65.0	0.8	0.04	0.058

In all the cases oxidant was added to the high-carbon ferrochrome in quantities theoretically necessary for the carbon oxydation.

It was mentioned above that it is impossible to receive ferrochrome with such a low carbon content using silicothermic methods. Consequently, refining of chromium in a solid state goes quicker and is more complete than in a liquid state, though the increase of temperature should have accelerated the oxidation of carbon. Practically all carbon in ferrochrome is gathered in carbides, which collect on the grains boundaries. And the fracture originates, first of all, along these boundaries when the sample is crushed or broken, in other words - after crushing of high-carbon ferrochrome the carbides are found on the surface of the particles. Formed under pressure into rods, the carbides are placed in close contact with the oxidant. In this case the activity of reagents is equal to one; in a liquid solution it is naturally lower. Increase of the activity of reagents accelerates the reaction.

New method of production of ferrochrome containing no carbon makes it possible to produce basically new alloy of a superior quality and simplifies the technique of ferrochrome production. Indeed, as shown on fig.7 it is necessary to use three furnaces in silicothermic method of low-carbon ferrochrome production - one for making ferrochrome with the highest carbon content, second - for making silicochrome, and third - for production

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of low-carbon ferrochrome by means of refining silicochrome. We can state that the expenses on installation of the equipment for crushing of high-carbon ferrochrome and the oxidant and also for preparing of briquettes that are necessary for the alloy production in vacuum, are much lower than the cost of an arc furnace. Narrowing of the list of raw materials and sharp decrease in the quantity of slags resulting from the utilization of vacuum in low-carbon ferrochrome production - these are additional factors that make the alloy cheaper.

A.A. Vertman [8] in laboratory found a possibility of producing chrome of a composition similar to that of the electrolytic chrome, using reduction by carbon of chrome oxide in vacuum.

Ductile vanadium was produced by A.U. Poljakov [9] by reduction of vanadium trioxide by carbon in vacuum.

The vacuum furnaces will undoubtedly find a wide application in ferroalloys and metals production.

4. Treatment of liquid steel in vacuum.

Though during the last several years the utilization of vacuum furnaces has considerably grown, together with their capacity, we can not yet count on annual production by them of hundreds of thousands tons of steel, due to complexity and high cost of basic equipment and the necessity to use electricity as a source of heat.

In 1941 a new and simpler method of application of vacuum in steel industry was proposed. Essentially, the proposal was: liquid steel produced in any type of furnace is subjected to a treatment in vacuum in order to reduce its oxygen, nitrogen and hydrogen contents, and the treatment can take place while keeping the ladle in a special chamber or while pouring the steel into ingot moulds.

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Industrial tests of one of the proposed methods were conducted by L.M. Novik together with the staff of Enakievsky metallurgical plant and of the "Dneprospetsstal" plant. [10, 11]. At Enakievsky metallurgical plant they subjected to vacuum treatment bessemer steel in a ladle of 16 tonn capacity. The vacuum above the liquid steel was created with the help of water rotating pumps which provide the residual pressure of about 70 mm Hg. The steel was kept in vacuum for 12-14 minutes. Before the pouring the vacuum was removed and the steel in the ladle deoxidized by ferromanganese. In the molds the steel made some shrinkage characteristic for the deoxidized steel.

Change of oxygen and nitrogen contents in a reaming bessemer steel during the process of vacuum treatment is shown on fig. 8. As we can see the oxygen content decreases 4-10 times after the vacuum treatment; nitrogen content - by 30-50 per cent. Reduction of the content of those elements in bessemer steel, especially that of nitrogen considerably lowers the tendency of embrittlement at low service temperatures, in other words, allows for wider application of this steel.

The fig. 9 shows Bauman prints of billets received after rolling of bessemer steel ingots: a - non-treated steel, b - steel treated in vacuum.

The absence of strongly pronounced segregation in the billet produced from vacuum treated steel testifies its superior quality.

At the "Dneprospetsstal" the vacuum treatment was used in production of transformer and construction steel in arc furnaces. At first the chambers here were equipped with water ^{ta} rotating pumps which could not produce high vacuum. As a rule the length of vacuum treatment amounted to 10 minutes, while 5-7 minutes

after the pumps were started the pressure inside of the chamber amounted to 60-70 mm Hg. Later on after installation of one oil pump to each chamber the residual pressure was brought down to 30-35 mm Hg.

The cheme of the chamber for the vacuum treatment of liquid steel in $\frac{1}{25}$ ~~kg~~ ladle is presented on fig. 10.

Before the application of vacuum treatment, to avoid production of unsound ingots the process of heat was conducted at reduced temperatures which led to overoxidation of steel and slowed down the desulphuration. The vacuum treatment of this steel prevents origination of unsound ingots and makes it possible to conduct the heat at higher temperatures. In this way the production of transformer steel with lower carbon, oxygen and sulphur contents was achieved.

All of them are harmful admixtures that lower the properties of steel.

Fig. II. shows distribution of heats according to the carbon and sulphur content of the transformer steel before and after introducing the vacuum treatment. All the heats are also divided into 3 periods: first - prior to the application of vacuum treatment; second - september-november 1955 - treatment in vacuum created by water rotating pumps; third (December 1955 - February 1956) - treatment in vacuum created by oil pumps. In brackets the number of heats in separate periods is given. The data presented on fig. II shows that if before the vacuum treatment the steel of 90% of the heats contained more than 0.04% of carbon and 0.007% of sulphur, after the application of vacuum treatment the steel of more than 90% of the heats contained not more than 0.02% of carbon and 0.005% of sulphur.

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Higher degree of purity of the transformer steel resulted in a decrease of watt losses. Before the vacuum treatment of transformer steel the output of 330 type steel amounted to 49.2 per cent; during the first period of treatment - 91.4% and during the second period - 93.5 percent.

The vacuum treatment favourably influenced the quality of the special purpose construction steel. A major defect of these steels is the presence in them of haircracks, originating due to the presence in the steel of hydrogen and nonmetallic inclusions. Ten minutes treatment of steel in a ladle under the pressure of about 30 mm Hg reduced the hydrogen content and consequently the possibility of haircracks origination.

The obtained results show that at present the metallurgists have a simple but effective means of improving the quality of many steels. The necessary arrangements for the vacuum treatment of liquid steel can be easily made on any metallurgical plant, and the treatment itself does not interrupt the normal routine of production. The vacuum treatment of liquid steel not only improves its properties but also gives an opportunity of increasing the output of steel furnaces because it reduces the length of a heat.

5. Pouring of steel in vacuum and in an atmosphere of inert gases.

The vacuum treatment of liquid steel is only a stage in the general system of measures providing for production of steel with the minimum gas content. The improvements achieved at this stage can be lost as a result of a secondary oxydation of steel in the air during its pouring. Therefore the pouring of vacuum treated steel in vacuum or in an atmosphere of an inert gas becomes quite indispensable.

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Fig. 12 shows **one** of the suggested devices for pouring of steel in an atmosphere of argon. After the molds are placed upon the bottom plate the cover is placed upon them and the air is evacuated from the chamber, which is then filled with argon. After placing the ladle above the chamber the aluminium plate separating the chamber from the atmosphere is melted by the stream of steel and the pouring goes on in the atmosphere of argon.

First tests of this device showed that after pouring heat-resistant steel, the received ingots required almost no further machining. All the ingots of this steel produced in the air are subjected to abrading which causes considerable losses of the expensive metal.

Fig. 13. shows : a - surface of an ingot produced by the old method and b - cast with the help of the above mentioned device utilizing the protective atmosphere of argon.

Application of such a device leads to a considerable reduction of the inert gas (argon) consumption. As a matter of fact less expensive nitrogen can be used as inert gas in pouring of a number of steels.

6. The immediate tasks.

We are at the very beginning of wide application of vacuum in steel production. Successful and rapid introduction of new methods into every-day practice largely depends upon the efforts of machine builders, electrical engineers and metallurgists.

A major task is to find refractory materials which can be used for production of crucibles for vacuum furnaces. Production of steel with the minimum content of impurities is possible only on the condition of absence of chemical interaction of molten metal with the furnace lining. In the majority of cases the mag-

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nesium oxide linings will evidently prove inapplicable, because the magnesium produced as a result of reduction of this oxide volatilizes, and the oxygen or oxides produced dissolve in the metal. Fig. II. shows that after remelting of chrome-nickel steel in vacuum its oxygen content increases, and the longer is it kept in vacuum, the higher is the oxygen content [12]. Absolute oxygen content in stainless steel turns out to be close to the limit of oxygen saturation for this steel. [13, 14].

More attention should be paid to the research of processes going on in vacuum furnaces. The kinetic of the purification of metal from admixtures - carbon, oxygen, sulphur, phosphorus etc., should be studied.

To determine the optimal methods of steel production in vacuum furnaces, it is necessary to study the behaviour of separate components of molten metal in vacuum.

The control of the process of melting in vacuum will be considerably simplified, if methods of temperature of the molten metal control and its composition control are developed.

The degree of purification of liquid steel from oxygen, nitrogen and hydrogen during the vacuum treatment depends on the existence of favourable conditions for their removal. High hydrostatic pressure in ladles of, say, 200 tonn capacity will be an obstacle for exhalation of gases from steel. It is necessary to use on the plants ladles with induction coils. Stirring of molten metal in the ladle will help to overcome the adverse influence of hydrostatic pressure. A ladle equipped with an induction coil can be kept under vacuum longer without the danger of overcooling the steel.

It is necessary to find cheap refractory materials of high

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quality for making ladle linings and stoppers because greater wear of refractory materials can be expected as a result of vacuum treatment of steel in the ladle.

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Table I.**CHEMICAL ANALYSIS OF TRANSFORMER STEEL**

Steel produced: NN of:		% %					:
in	heats:	C	Si	O	N	H	: nonmetallic in-
							: clusions.
conventional furnace	1	0,040	3,50	0,0192	0,0056	0,00020	0,0390
	2	0,040	3,53	0,0177	0,0030	0,00030	0,0340
	3	0,030	3,24	0,0195	0,0044	0,00040	0,0500
	4	0,030	2,75	0,0145	0,0048	0,00030	-
	5	0,025	2,63	0,0182	0,0028	0,00020	0,0380
vacuum furnace	6	0,015	3,12	0,0019	0,0028	0,00005	0,0042
	7	0,020	2,92	0,0026	0,0042	0,00005	0,0070
	8	0,020	3,35	0,0022	0,0037	0,00005	0,0050
	9	0,020	3,53	0,0025	0,0028	0,00005	0,0050

Table 2.

COERCITIVE FORCE OF TRANSFORMER STEEL (in oersteds)

N N of heats	Thickness of plates in mm.	Thickness of plates :		
		0,32	0,20	0,08
35673		0,204	0,247	0,256
35668		0,237	0,260	0,290
27941		0,290	0,376	0,315
37947		0,314	0,234	-
33367		0,230	0,371	0,277

Table 3

CHEMICAL ANALYSIS ~~OF STEEL~~ AND PROPERTIES OF CHROMIUM-NICKEL STAINLESS STEEL.

No. of heats:									Resistance of steel to intercrystalline corrosion.	Weight losses of submerged steel during four 25 hour cycles, gr/m ² /hour.
	C	Cr	Ni	Mn	Si	S	P			
3816	0,07	17,90	8,73	0,24	0,33	0,014	-	-	-	0,620
3823	0,09	16,36	9,30	0,26	0,42	0,013	-	-	-	12,060
3825	0,07	16,67	9,05	0,18	0,41	0,016	-	-	-	1,900
4124	0,08	17,48	8,98	0,34	0,41	0,017	-	-	-	4,432
4125	0,09	17,91	7,76	0,48	0,66	0,014	-	-	-	3,600
3816	0,07	17,50	9,02	0,32	0,47	0,013	0,24	+	-	12,110
4016	0,09	17,08	8,70	0,53	0,59	0,016	0,32	+	-	23,950
4205	0,02	18,95	8,85	0,69	0,19	0,015	-	+	-	0,126
4205	0,03	19,21	8,38	0,57	0,17	0,017	-	+	-	0,131
4205	0,02	19,28	8,14	0,71	0,26	0,013	-	+	-	0,138
4205	0,01	19,05	8,19	0,61	0,22	0,012	-	+	-	0,239
4205	0,02	19,17	8,64	0,71	0,34	0,012	-	+	-	0,171

Table 4.

**CHEMICAL ANALYSIS OF LOW CARBON FERROCHROMIUM PRODUCED
IN VACUUM**

Oxidant	%							
	C	Cr	Si	Si+ SiO2	S	P	Ni	
Chromium oxide	0,01-0,02	74-75	0,4-0,5	-	0,03	0,03	-	
Silica	0,03	62-64	-	7,6- -8,5	-	-	-	
Chromium ore	0,02	63-65	1,2-1,4	-	-	-	-	
Nickel protoxide	0,03	47-51	-	-	-	-	26 - 28	



Fig 136

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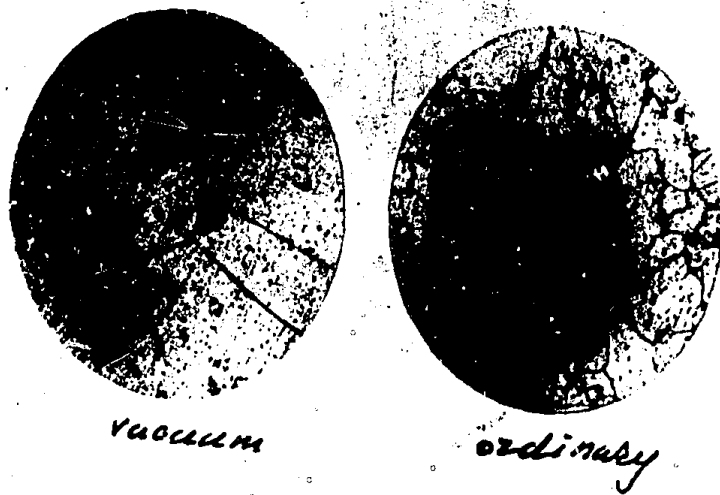
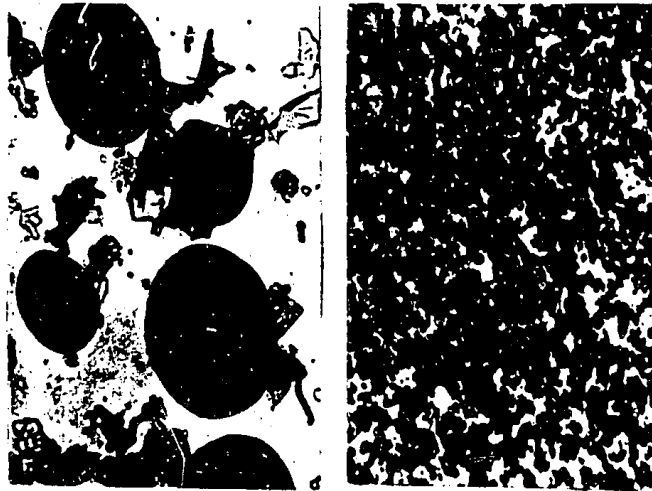


Fig. 5 -

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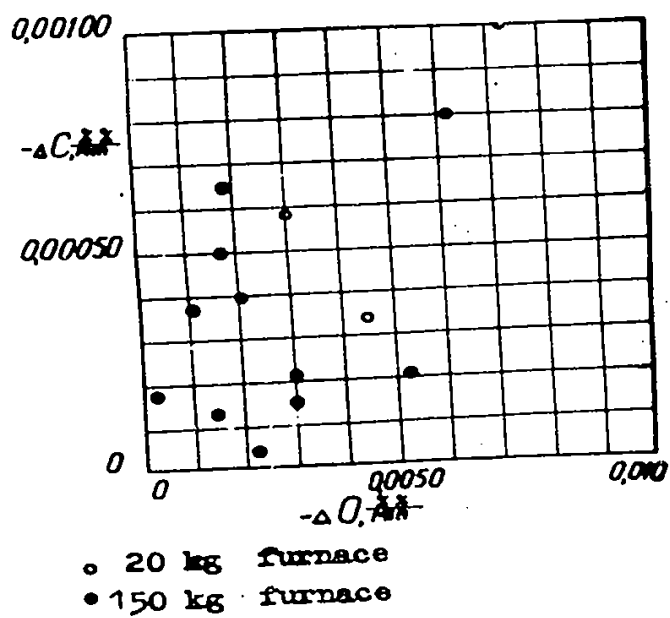
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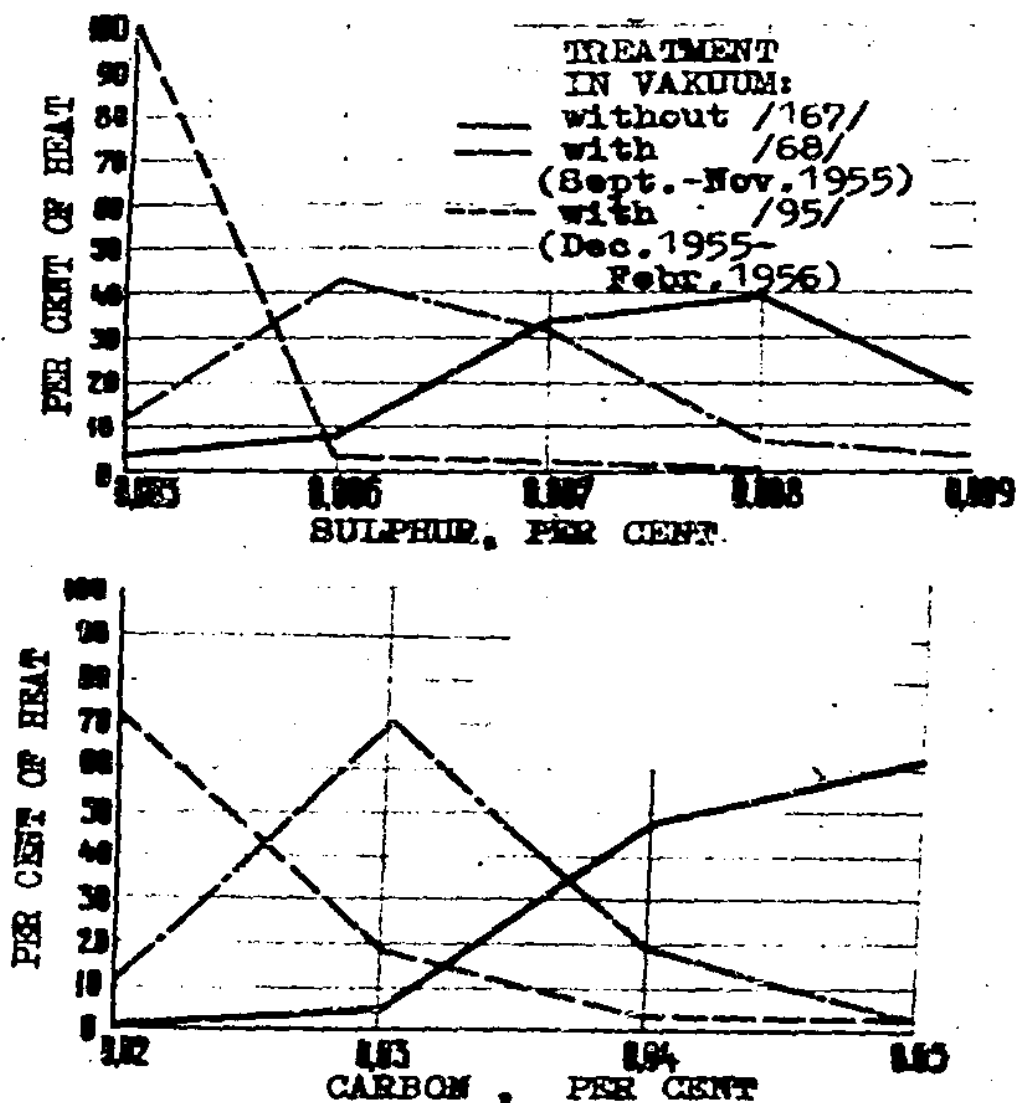
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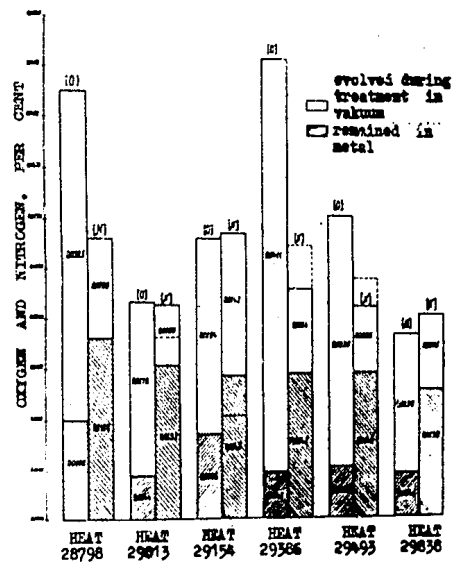
b

Fugy

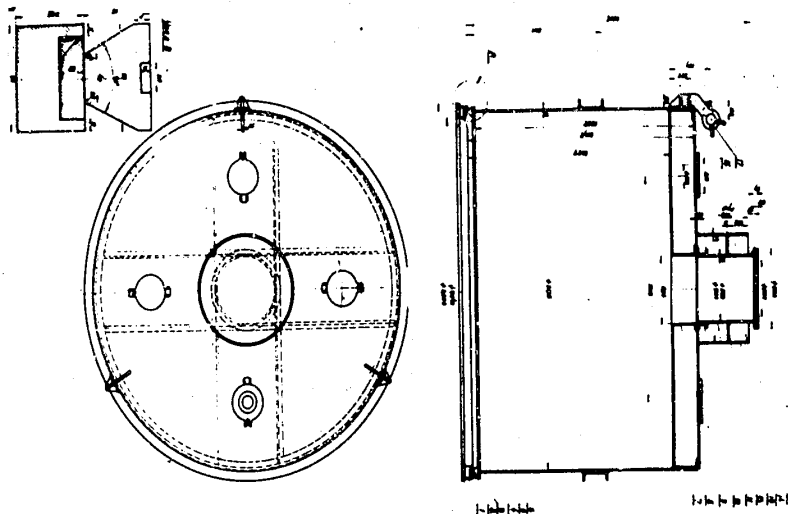


F. 1





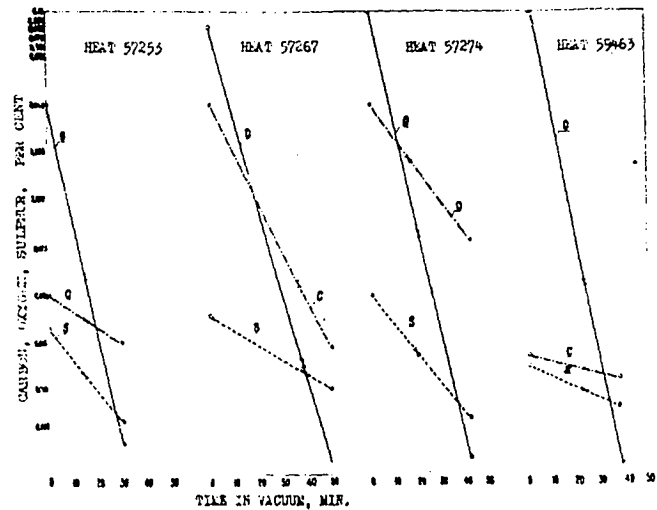
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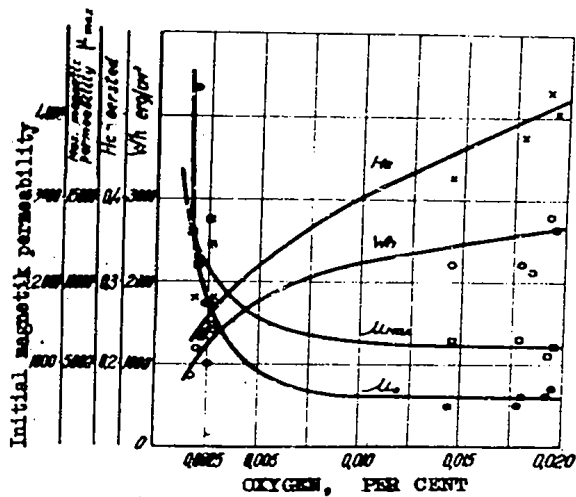
POOR ORIGINAL

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Fig 12



F. 19.3



POOR ORIGINAL

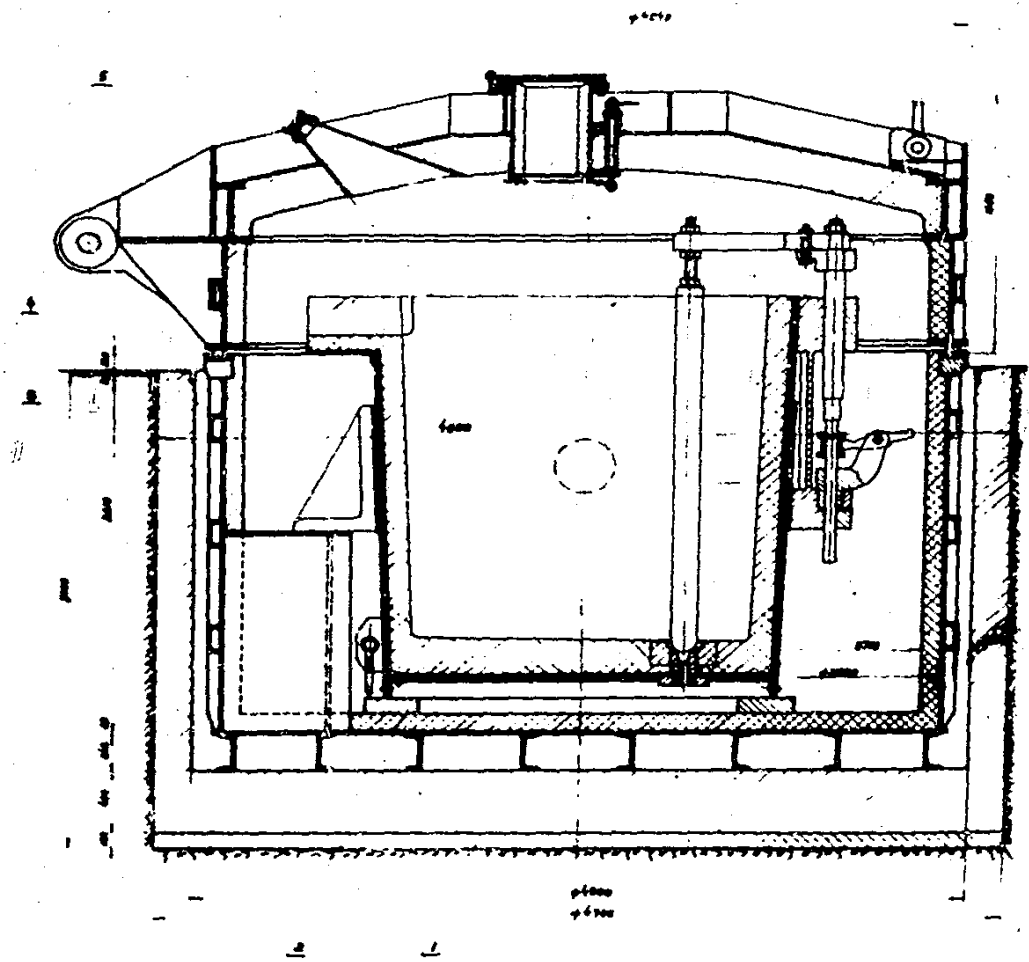


Fig 10